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(54) [Title of the Invention] METHOD FOR FABRICATING AN OPTICAL WAVEGUIDE WITH A LENS

(57) [Claim]

[Claim 1]

A Method for fabricating an optical waveguide with a lens, characterized in that the method comprises the steps of:

forming an undercladding layer on a substrate;

depositing a core layer on the undercladding layer and then photolithographically patterning the core layer using a single mask to simultaneously form a core and a lens that has a convex surface projecting from an end face of the core in a direction parallel to the plate plane of the substrate; and

depositing an overcladding layer on the core, lens, and undercladding layer and then patterning the overcladding layer to cover the both sides and top of the core without covering the top and end faces of the lens, leaving them exposed to the outside.

[Detailed Description of the Invention]

[0001]

[Technical Field to which the Invention Belongs]

The present invention relates to a method for fabricating an optical waveguide used in the field of optical communication or the like and configured to easily provide a good coupling efficiency when light from a light emitting device or the like

is coupled into the optical waveguide.

[0002]

[Prior Art]

Fig. 3 shows one example of a conventional optical arrangement that couples an optical waveguide and a light emitting device, in which the optical waveguide 20 is formed on one side of a substrate 10 and a laser diode (LD) 30 light emitting device is mounted on the other side. The optical waveguide 20 comprises an undercladding layer 21 formed on the substrate 10, core 22 having predetermined width and height and formed on the undercladding layer 21, and an overcladding layer 23 formed to cover the both sides and top of the core 22.

[0003]

The laser diode 30 is mounted on an electrode 11 formed on the substrate 10 with high precision using, for example, an alignment marker. In this example, the laser diode 30 and the optical waveguide 20 are directly coupled. An electrode 12 formed adjacent to the electrode 11 is wirebonded to a top surface electrode of the laser diode 30, but the wire is not shown in this diagram. The electrodes 11, 12 are made of gold (Au) or the like. In Fig. 3, reference number 13 denotes a solder layer and reference number 31 denotes laser light emitted from the laser diode 30.

[0004]

In the arrangement where the laser diode is directly coupled to the optical waveguide as shown in Fig. 3, it is difficult to fabricate, for example, a high power integrated laser/waveguide optical module because of a large coupling loss due to the mismatch of the mode field diameters at the connection of the laser diode and the optical waveguide. Alternatively, a lens can be placed between the laser diode and the optical waveguide such that they are coupled via the lens with increased coupling efficiency. In this case, the lens, optical waveguide and laser diode must be aligned with respect to each other with high precision, which requires active alignment of those components that involves more assembly processes, contributing to higher cost.

[0005]

On the other hand, Fig. 4 shows an arrangement conventionally proposed for coupling an optical waveguide and a light emitting device (laser diode), where the same characters refer to corresponding parts in Fig. 3. In this example, the optical waveguide 20 formed on the substrate 10 has an end face facing the laser diode 30 and formed with a convex portion 24 so that the convex surface faces toward the laser diode 30, creating a lens effect at the end face of the core 22 (see the patent document 1, for example). Fig. 5 shows the fabrication processes of the optical waveguide 20 having this convex portion 24 at its end face in order of execution.

Each process will be described below.

[0006]

(1) The undercladding layer 21 and the core layer are sequentially formed and laminated on the substrate 10, and the core layer is patterned to form the core 22.

(2) The overcladding layer 23 is formed to cover the both sides and top of the core 22.

(3) An etching mask 25 is formed on the top of the overcladding layer 23. The etching mask 25 is with a convex portion 25a at its edge.

(4) The overcladding layer 23, core 22, and the undercladding layer 21 are etched through the etching mask 25 thereon to form the convex portion 24 at the end face of the optical waveguide 20.

By removing the etching mask 25, the optical waveguide 20 with the convex portion 24 at its end face as shown in Fig. 4 is completed.

[0007]

[Patent Document 1]

JP-A-2000-39531 (Figs. 1 to 5)

[0008]

[Problems that the Invention is to Solve]

A core integrally formed with a lens (lens structure) as described above eliminates the need of a labor-intensive active alignment which is required in the case of placing a

lens which is a discrete component. Although this can achieve an increased coupling efficiency at a low cost when the optical waveguide is coupled to, for example, a laser diode, the conventional example shown in Figs. 4 and 5 has the following problem. That is, in the conventional example as shown in Fig. 5, the core 22 and the overcladding layer 23 are formed and etched using the etching mask 25 to form the convex portion 24 at the end face of the optical waveguide 20, which requires highly precise alignment of the convex portion 25a of the etching mask 25 and the minute core 22 embedded in the overcladding layer 23. This alignment precision is difficult to achieve, which may result in a situation where good performance and coupling efficiency cannot be obtained as a result of the misalignment of the etching mask 25.

[0009]

In view of this problem, an object of the invention is to provide a method for fabricating an optical waveguide with a lens integrally formed with a core, wherein there is no misalignment between the core and the lens so that a good coupling efficiency can be easily (at a low cost) achieved when the optical waveguide with the lens is coupled to an optical device such as a laser diode.

[0010]

[Means for Solving the Problems]

According to the invention, an optical waveguide with

a lens is fabricated by the steps of: forming an undercladding layer on a substrate; depositing a core layer on the undercladding layer and then photolithographically patterning the core layer using a single mask to simultaneously form a core and a lens that has a convex surface projecting from an end face of the core in the direction parallel to the plate plane of the substrate; and depositing an overcladding layer on the core, lens, and undercladding layer and then patterning the overcladding layer to cover the two sides and top of the core without covering the top and end faces of the lens so that they are exposed.

[0011]

[Mode for Carrying out the Invention]

An embodiment of the invention will be described by way of an example with reference to the drawings. Fig. 1 shows an arrangement that couples one exemplary configuration of an optical waveguide with a lens fabricated according to the invention to a laser diode. In the figure, the same characters refer to corresponding parts in Fig. 3 and their detailed description will be omitted. In this example, a core 22 and a lens 26 formed to have a convex surface projecting from an end face of the core 22 in the direction parallel to the plate plane of a substrate 10 are integrally formed by simultaneous photolithographical patterning using a single mask.

[0012]

An overcladding layer 23 is formed so that it does not cover the lens 26 and so that the top and end faces thereof are both exposed. Fig. 2 shows the fabricating processes of the optical waveguide 20 with the lens 26 in order of execution in which a photosensitive resin is used as an optical waveguide material. Each process will be described with reference to Fig. 2. Acrylic- or epoxy-based UV-curable resins can be used as the photosensitive resins. The relative refractive index differences between the core 22, undercladding layer 21, and overcladding layer 23 Δn are, for example, on the order of 0.3% to 0.2%.

[0013]

(1) The undercladding layer 21 is deposited on the substrate 10 by spin coating, and then cured by exposure to light. A silicon substrate or the like is used for the substrate 10.

(2) The core layer 22′ is deposited on the undercladding layer 21 similarly by spin coating.

(3) The core 22 and lens 26 are simultaneously patterned by single mask exposure and development. The core 22 is patterned to have, for example, a width and height of approximately 3 to 8 μm. The lens 26 is patterned into a semicircular shape in this example.

(4) The overcladding layer 23 is spin coated thereon.

(5) The overcladding layer 23 is patterned by exposing

and developing through a mask through which the lens 26 is exposed.

[0014]

Through these processes, the optical waveguide 20 with the lens 26 is completed. In the above processes, the top of the lens 26 is not covered with the overcladding layer 23, but rather is exposed in order to increase the refractive index with the outside and produce a lens effect. For example, the relative refractive index difference Δn is on the order of 0.3% to 2% when the top of the lens 26 is covered with the overcladding layer 23, while Δn increases to 30% when the outside medium is air. In the above fabricating processes, although the undercladding layer 21, core layer 22', and overcladding layer 23 are all applied and deposited by spin coating, the spin coating can be replaced with dipping or the like.

[0015]

The optical waveguide 20 with the lens 26 fabricated in the above processes does not cause positional misalignment with the core 22 because the lens 26 integrated to the core 22 has been formed by simultaneous patterning with the core 22. Therefore, when the optical waveguide 20 with the lens 26 is coupled to the laser diode 30 as shown in Fig. 1, a good coupling efficiency is achieved between the lens 26 and the laser diode 30, and the laser light 31 emitted from the laser diode 30 is collimated by the lens 26 and enters into the core 22 with high

efficiency. The radius R of the lens 22 with respect to the horizontal direction of the light beam of the laser light 31 (the direction parallel to the plate plane of the substrate 10) can be determined so that the mode field diameter of the optical waveguide 20 is converted to that of the laser diode 30. That is, the determination of the radius R determines the focal length f accordingly. Regarding those values, however, there exist optimal values matched to the horizontal aperture angle of the laser diode 30.

[0016]

On the other hand, because the lens effect is only available in the horizontal direction in this example, the field diameter of the optical waveguide 20 for the vertical direction monotonously increases in proportion to the distance from the optical waveguide 20 along the aperture angle of the end face of the optical waveguide 20. Therefore, the optimal distance for the vertical direction between the laser diode 30 and the optical waveguide 20 in the conventional example that does not include a lens as shown in Fig. 3 remains optimal for the vertical direction. In general, since the optimal distance for the vertical direction and the above optimal distance (f) for the horizontal direction do not coincide, a distance and radius of the lens advantageous with respect to the overall amount of light are selected appropriately from intermediate values between these two optimal values.

[0017]

The optical waveguide material is not limited to a UV-curable photosensitive resin as used in the example described above, but may be organic materials such as polyimide. In this case, the simultaneous patterning of the core 22 and lens 26 is carried out by spin coating a plasma-resistant photoresist on the core layer 22′ made of polyimide, exposing and developing the resist through a mask having the shape of the core 22 and lens 26, and plasma etching the core layer 22′ by reactive ion etching (RIE) using the photoresist as a mask.

[0018]

[Advantage of the Invention]

As described above, according to the invention, the core and the lens are simultaneously patterned and integrally formed in a single photolithography process, so that when coupled to an optical device such as a laser diode, cumbersome alignment as required in the case of using a discrete lens is not necessary, providing a good coupling efficiency at a low cost. Furthermore, unlike the conventional optical waveguide configuration in which a convex portion is formed at an end face of the optical waveguide to provide a lens effect at the end face as shown in Fig. 4, there is no misalignment between the core and the lens. In this regard, according to the invention, the lens can be placed with respect to the core in a highly precise and simple manner. As any shape of lens can

be easily produced by designing a mask accordingly, an optimal optical waveguide with a lens can be easily fabricated depending on applications.

[Brief Description of the Drawings]

[Fig. 1] Fig. 1A and 1B are plan and side views, respectively, illustrating the arrangement that couples an optical waveguide with a lens to a laser diode, fabricated according to the invention.

[Fig. 2] Fig. 2 is a view for explaining the fabricating processes of the optical waveguide with the lens of Fig. 1.

[Fig. 3] Fig. 3A and 3B are plan and side views, respectively, illustrating a conventional arrangement that couples an optical waveguide and a laser diode.

[Fig. 4] Fig. 4 is a perspective view illustrating an arrangement conventionally proposed for coupling of an optical waveguide and a laser diode.

[Fig. 5] Fig. 5 is a view for explaining the fabricating processes of the optical waveguide of Fig. 4 having a convex portion on an end face.

[Fig. 1]

10 SUBSTRATE

11 ELECTRODE

12 ELECTRODE

20 OPTICAL WAVEGUIDE

21 UNDERCLADDING LAYER

22 CORE

23 OVERCLADDING LAYER

26 LENS

30 LASER DIODE

31 LASER LIGHT

[Fig. 2]

10 SUBSTRATE

21 UNDERCLADDING LAYER

22 CORE

22′ CORE LAYER

23 OVERCLADDING LAYER

26 LENS

[Fig. 3]

10 SUBSTRATE

11 ELECTRODE

12 ELECTRODE

20 OPTICAL WAVEGUIDE

21 UNDERCLADDING LAYER

22 CORE

23 OVERCLADDING LAYER

30 LASER DIODE

31 LASER LIGHT

[Fig. 4]

10 SUBSTRATE

20 OPTICAL WAVEGUIDE

22 CORE

24 CONVEX PORTION

30 LASER DIODE

[Fig. 5]

10 SUBSTRATE

20 OPTICAL WAVEGUIDE

21 UNDERCLADDING LAYER

22 CORE

23 OVERCLADDING LAYER

24 CONVEX PORTION

25 ETCHING MASK

Drawing selection [drawing 1]

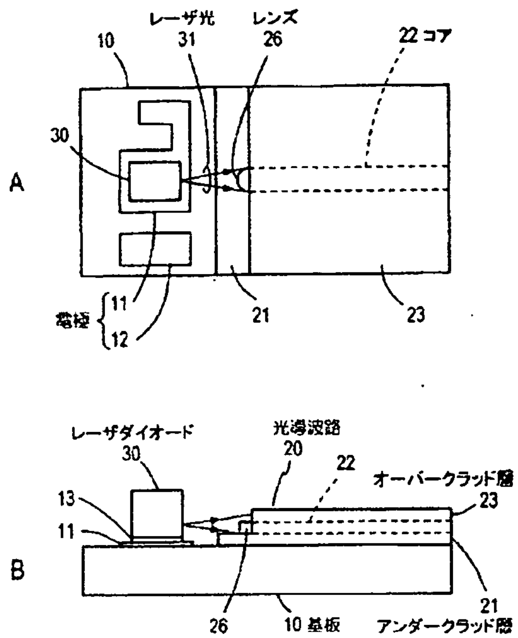
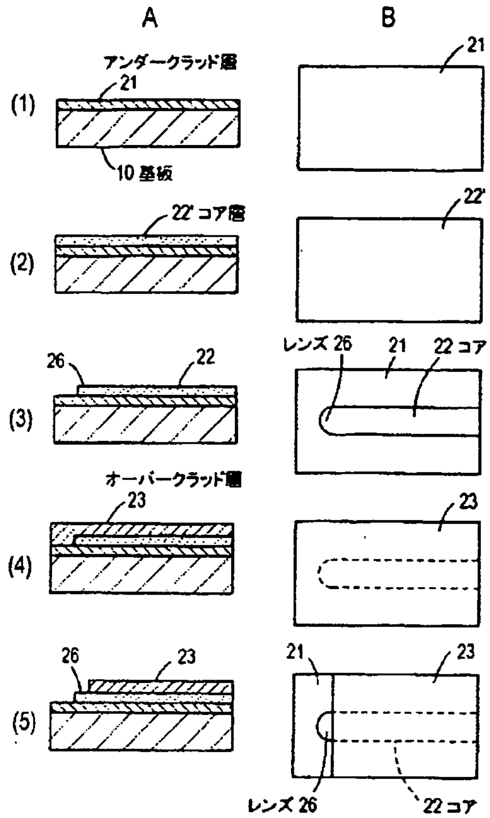


図1

[Translation done.]

Drawing selection drawing 2



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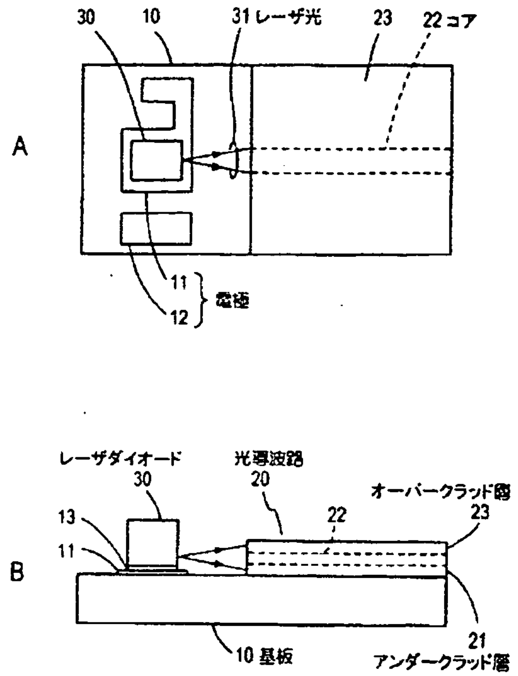
[Translation done.]

Drawing selection drawing 3



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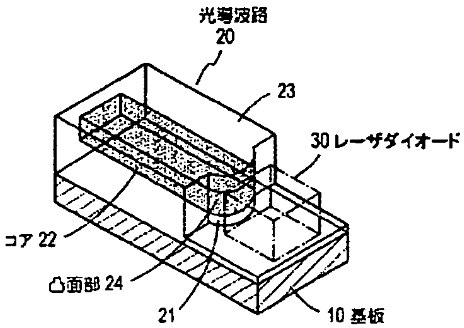
[Translation done.]

Drawing selection drawing 4



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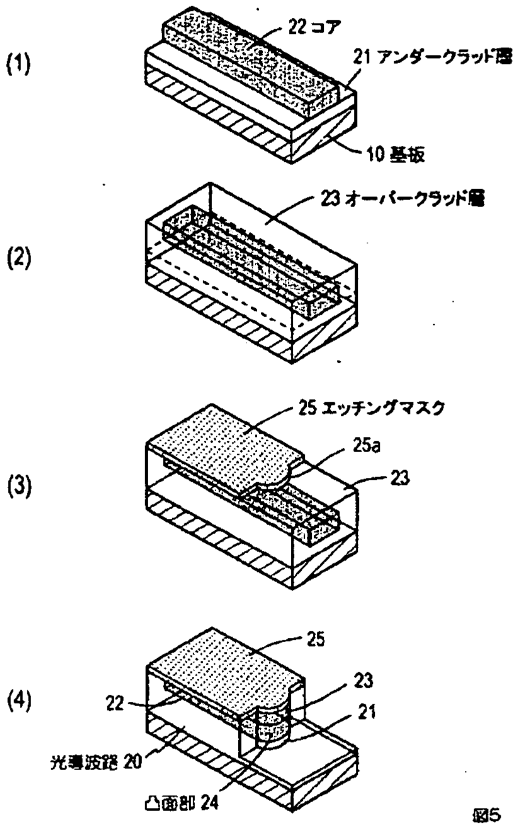

図5

[Translation done.]